Earth's Environmental Systems
and Human Population Growth

A Senior Thesis

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ABSTRACT

Exponential growth of the human population has led to increasing alteration of the earth's environmental systems. Models of some major biogeochemical and climate systems are evaluated. It will take the contributions of many different scientific disciplines to improve the current state of knowledge concerning the complex, interacting systems which regulate our environment. Stabilizing the population of the developing countries can best be achieved through a modified version of the demographic transition which emmulates mature ecosystem attributes.

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Introduction

Exponential growth of the human population has led to the creation of a new Earth/Human environmental system. This new combination has not yet been described in sufficient detail to determine what our role will be. We are altering complex, interacting systems of energy, matter, and life that have evolved over the past four and a half billion years. Study of this complexity will require the full participation of the many different scientific disciplines if we are to adapt to changes, some of which we are responsible for making. Interest in this problem has already led to the creation of a wide spectrum of international organizations and activities (see Figure 1).

One of the most important characteristics of the new Earth/Human environmental system is the distribution of population growth: it is predominantly a phenomenon of those countries with developing economies. Projections for the next fifty years predict these countries will add more people than now inhabit the earth (Malone, 1991). Such growth could present dangers to the environment which are

BAHC - Biospheric Aspects of the Hydrological Cycle
COMAR - Coastal Marine Project
EMEP - Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
EPC - The European Palaeoclimate and Man since the Last Glaciation
EPOCH - European Programme on Climatology and Natural Hazards
GAW - Global Atmosphere Watch
GCTE - Global Change and Terrestrial Ecosystems
GEMS - Global Environment Monitoring System
GEWEX - Global Energy and Water Cycle Experiment
GRID - Global Resource Information Database
HDGC - Human Dimensions of Global Change

IGAC - International Global Atmospheric Chemistry Programme
IGBP - International Geosphere-Biosphere Programme
IGCP - International Geological Correlation Programme
IGOSS - Integrated Global Ocean Station System
IHP - International Hydrological Programme
IPCC - Intergovernmental Panel on Climate Change
ISCCP - International Satellite Cloud Climatology Project
JGOFS - Joint Global Ocean Flux Study
MAB - Man and the Biosphere Programme
PAGES - Past Global Changes
TOGA - Tropical Oceans and Global Atmosphere Programme
WCAP - World Climate Application Programme
WCDP - World Climate Data Programme
WCIP - World Climate Impact Studies Programme
WCP - World Climate Programme
WCRP - World Climate Research Programme
WOCE - World Ocean Circulation Experiment
WWW - World Weather Watch

ii) Organizations

CCCO - Committee on Climatic Changes and the Ocean
ECE - Economic Commission for Europe (United Nations)
EEC - European Economic Community
ESF - European Science Foundation
FAO - Food and Agriculture Organization
IABO - International Association for Biological Oceanography
IAHS - International Association of Hydrological Sciences
ICSU - International Council of Scientific Unions
INTECOL - International Association for Ecology
IOC - Intergovernmental Oceanographic Commission (UNESCO)
ISSC - International Social Science Council
IUGS - International Union of Geological Sciences
SCAR - Scientific Committee on Antarctic Research
SCOR - Scientific Committee on Ocean Research
UNEP - United Nations Environment Programme
UNESCO - United Nations Educational, Scientific and Cultural Organization
WMO - World Meteorological Organization

ACTIVITY	PARTICIPATING ORGANISATIONS					
a) WCP	WMO	ICSU		UNEP	FAO	
b) WCRP	WMO	ICSU				
b1) TOGA	WMO	ICSU(SCOR*)	UNESCO(IOC*)			
b2) WOCE	WMO	ICSU(SCOR*)	UNESCO(IOC*)			
b3) GEWEX	WMO	ICSU				
b4) ISCCP	WMO	ICSU				
c) WCAP	WMO					SCAR
d) WCDP	WMO	ICSU	UNESCO(IOC)	UNEP	FAO	
e) WCIP	WMO	ICSU		UNEP		
f) IGOSS	WMO		UNESCO(IOC)			
g) WWW	WMO					
h) GAW	WMO					
i) IGBP	WMO	ICSU				
i1) BACH	WMO	ICSU				
i2) GCTE		ICSU				
i3) IGAC	WMO	ICSU				
i4) JGOFS	WMO	ICSU				
i5) PAGES		ICSU				
j) IHP	WMO		UNESCO	UNEP		IAHS
k) MAB		ICSU	UNESCO			INTECOL
l) IGCP			UNESCO			IUGS
m) COMAR		ICSU	UNESCO			IABO
n) GEMS	WMO		UNESCO(IOC)	UNEP	FAO	
o) GRID				UNEP		
p) EPOCH						EEC
q) EPC						ESF
r) EMEP	WMO					ECE
s) HDGC						ISSC
t) IPCC	WMO			UNEP		

* Participation of SCOR and IOC is ensured through CCCO

Figure 1 Main international scientific activities related to global environmental change and participating organizations.

from da Cunha 1991

unprecedented. Stabilizing these populations will be crucial to the preservation of the global environment. By carefully promoting sustainable development of these regions cultural and social feedback mechanisms of population control can be enhanced (Boughey, 1974).

The next generation will live in a world vastly different from the present one. Human population increases will have profoundly changed the formerly 'natural' world into a new one. If we can come to a useful interpretation of the new world and devise successful, sustainable strategies for adapting to its changing conditions then it may be a world they can enjoy and pass on to future generations.

Earth/Human Systems Science

There is one opinion common to all researchers involved in the study of the Earth/Human system - more information is needed if we are to make valid predictions about future environmental conditions. An examination of the some of relevant studies into the characteristics of the system will demonstrate the extent of the current understanding of the system and what types of information are currently being sought.

History of the Earth System

Through the study of past changes in the earth system we can gain insights into how the new system may react to changes. Models of the present system can be tested by applying them to past conditions and seeing if they produce results that agree with the historical record. There are many types of evidence in the geologic record which preserve evidence of past climatic conditions.

Past changes in the earth system have had profound affects on environmental conditions. However, the time scale of factors such as changing geography due to plate tectonics or orbital periodicities of the earth (Degens, 1981) are only important when comparing past climates with today's. Other long-term changes in the history of the earth have been in the composition of the atmosphere. It is generally believed that the CO_2 content of the atmosphere has decreased over the lifetime of the earth. Related to the change in atmospheric CO_2 by several different feedback mechanisms (Kellogg, 1983; Walker, 1981; Lovelock, 1988) has been an increase in the luminosity of the sun of approximately 25-30% since the earth was formed.

The feedback mechanisms explain the relative consistency of the earth's climate despite of the change in solar output. By returning CO_2 to the atmosphere when we burn fossil fuel we are reversing this trend.

Paleoclimatology can be useful in testing climate models to evaluate their performance in terms of known changes in the past (Imbrie, 1985). Studies like McGowran's (1990) of the Eocene climate shifts between "greenhouse" and "icehouse" climate modes; Crowley's (1988) relationship of abrupt climate change with extinction events; and Broecker's (1990) examination of massive reorganizations of the ocean-atmosphere system that could have driven the last glacial cycles can help identify possible climatic thresholds we might approach in the future.

Biogeochemical Cycles

Models of the earth's biogeochemical cycles attempt to define the complicated fluxes of various elements between their sources and sinks in the environment. An example which treats how many of the cycles interact with each other is Likens' (1981) study of the biogeochemical cycles in terms of one watershed. Figure 2 depicts the global nitrogen cycle and is typical of way biogeochemical cycles are depicted.

Many of these cycles are being directly altered by human activity. These changes can have regional effects such as acid rain caused chiefly by human inputs of sulphur into the atmosphere. They can also create changes which are global in scale such as ozone depletion in the stratosphere by CFCs or enhance the greenhouse effect by combustion of fossil fuels.

Carbon cycle

Perhaps the most significant of the alterations we are making to the Earth/Human system is the increase in carbon dioxide in the environment caused by combustion of fossil fuels. This atmospheric trace gas is responsible for regulating the greenhouse properties of the atmosphere and ultimately the climate. The carbon cycle is intimately involved with biological processes making it very difficult to accurately define. Current models are unable to account for all the carbon fluxes since 1800 (Post, 1990). Even the change of seasons is reflected in the carbon cycle (Box, 1988). The condition of many carbon resevoirs can change from a source to a sink depending on climate conditions (Billings, 1982).

Carbonate-Silicate cycle

The carbonate-silicate cycle is a special case biogeochemical cycle which may have had a stabilizing effect on the earth's atmosphere (Walker, 1981). Briefly, the mechanism is a negative feedback loop in which atmospheric CO_2 increases cause warmer temperatures and drive the hydrological cycle faster producing more precipitation. Precipitation containing dissolved CO_2 weathers silicate rocks releasing Ca^{++} and Mg^{++} which are carried to the ocean. Once in the ocean the cations react with carbonate ions, precipitate, and become incorporated in the ocean sediments. Plate tectonic consumption of oceanic sediments returns the cations to the lithosphere and volcanoes return the carbon dioxide to the atmosphere. The importance of this model is that it can explain the stability of Earth's surface temperature over geologic time scales despite the 25-30% increase in solar luminosity. Geophysicists have used the carbonate-silicate cycle to discount the Gaia hypothesis' insistence that life controls the climate since the mechanism should work equally as well on a lifeless world (Kerr, 1988).

General Circulation Models(GCMs)

Since the advent of powerful computers capable of handling the huge number of calculations these models are composed of there has been a steady evolution in their ability to represent the state of the climate. GCMs divide the atmosphere and oceans into units of volume and describe their behavior in terms of equations of conservation of mass, momentum, energy, and two diagnostic equations for internal energy and thermodynamic state (Saltzman, 1985). The predictions of global warming are derived from GCM studies of the effects of increasing atmospheric CO_2. Despite the sophistication of the GCMs they still cannot prove that the climate has been altered by human activity. A major weakness has been the inability to determine whether clouds have a cooling or warming effect on climate. When GCMs can overcome these challenges they will be essential tools to manage the Earth/Human system.

The Gaia Hypothesis

James Lovelock has described the Gaia hypothesis in many ways (Schneider, 1990, Kirchner, 1990, Lovelock, 1988). Basically, the hypothesis states that the biota have exerted a stabilizing effect on the Earth's environmental conditions by actively regulating its complex biogeochemical mechanisms. Instead of attempting to reduce the system into finer, more accurately defined components the Gaian approach would be to look at the system as a whole, looking for cybernetic mechanisms, and search for trends such as the transfer of sulfur from the land to the sea, which led to the discovery of a complex feedback mechanism involving oceanic phytoplankton and the production of cloud condensation nuclei.

Lovelock has claimed to have improved upon the carbonate-silicate cycle by noting that is involved in both the deposition of carbonate sediments in the ocean as the shells of marine organisms and in the weathering of the rocks by creating elevated (10-40 times higher) concentrations of carbon dioxide in soils (Lovelock, 1988).

Critics of the hypothesis will grant that it is an inspiring concept but that it is too vague to be proven. Kirchner (1990) warns in a letter to *Nature* that Gaia is dangerous because it can be used to explain almost anything and if it is taken too seriously by science it will "lend a spurious air of scientific legitimacy to almost any reckless conjecture."

The Earth/Human System

Human population size will only be stabilized if a sufficient level of development can be spread to the majority of people. Failure to achieve stabilization would result in decreases in the environment's carrying capacity due to cycles of overloading by populations suffering occasionally disasterous death rates. The increased development required to avoid that fate will alter many of the earth's environmental systems. The current state of understanding of these systems is insufficient to make useful specific predictions. The general consensus among the GCMs (due to the way they treat increased CO_2 concentrations) is that with a doubling of carbon dioxide the global mean temperature would increase between 1.5°C to 4.5°C . Due to the noise in meteorological data significant change in global mean temperature has been extremely difficult to detect (Wiin-Nielsen, 1991). When James Hansen, director of NASA's Goddard Institute for Space Studies, gave testimony before the U. S. Senate Committee on Energy and Natural Resources in June of 1988 that global warming was detected and was already increasing the probability of extreme climate conditions such as heat waves, he was denounced by other scientists. "Projections make poor politics" (Ruckelshaus, 1989) and projections of the consequences of altering the earth's systems are all that the scientific community are able to provide at present. Improvement must be made in the capability to project what climate changes will occur if the human population of the future is going to cope effectively.

Human Alteration of Earth Systems

The degree of alteration of the environment caused by human activities can be described in three terms: size of population, broad set of technologies used to acquire resources, and the average per capita consumption of resources. Population growth is the one trend which is currently the most significant in our relationship with the environment. It is population which motivates the utilization of harmful technologies: resources which could be used to improve technology are needed to meet the immediate needs of the people. While population growth can diminish the average consumption of resources if no new resources are developed, it tends to promote the development of environmentally harmful, marginal resources.

Population Growth

Populations grow due to many different factors. Some are internal such as the composition of the population and some are external such as the availability of important resources. Below are some definitions of common terms used in dealing with the subject of populations.

Age pyramids which show the number of individuals in various age groups indicate the potential of a population to increase. The larger the portion of the population capable of reproducing, the larger its potential for increase. Figure 2 is an age pyramid for the developed and developing countries showing that the developing countries have a large capacity for population growth. The *growth rate* of a population is determined by the relationship between its *natality* or birth rate and its *mortality* or death rate. The growth

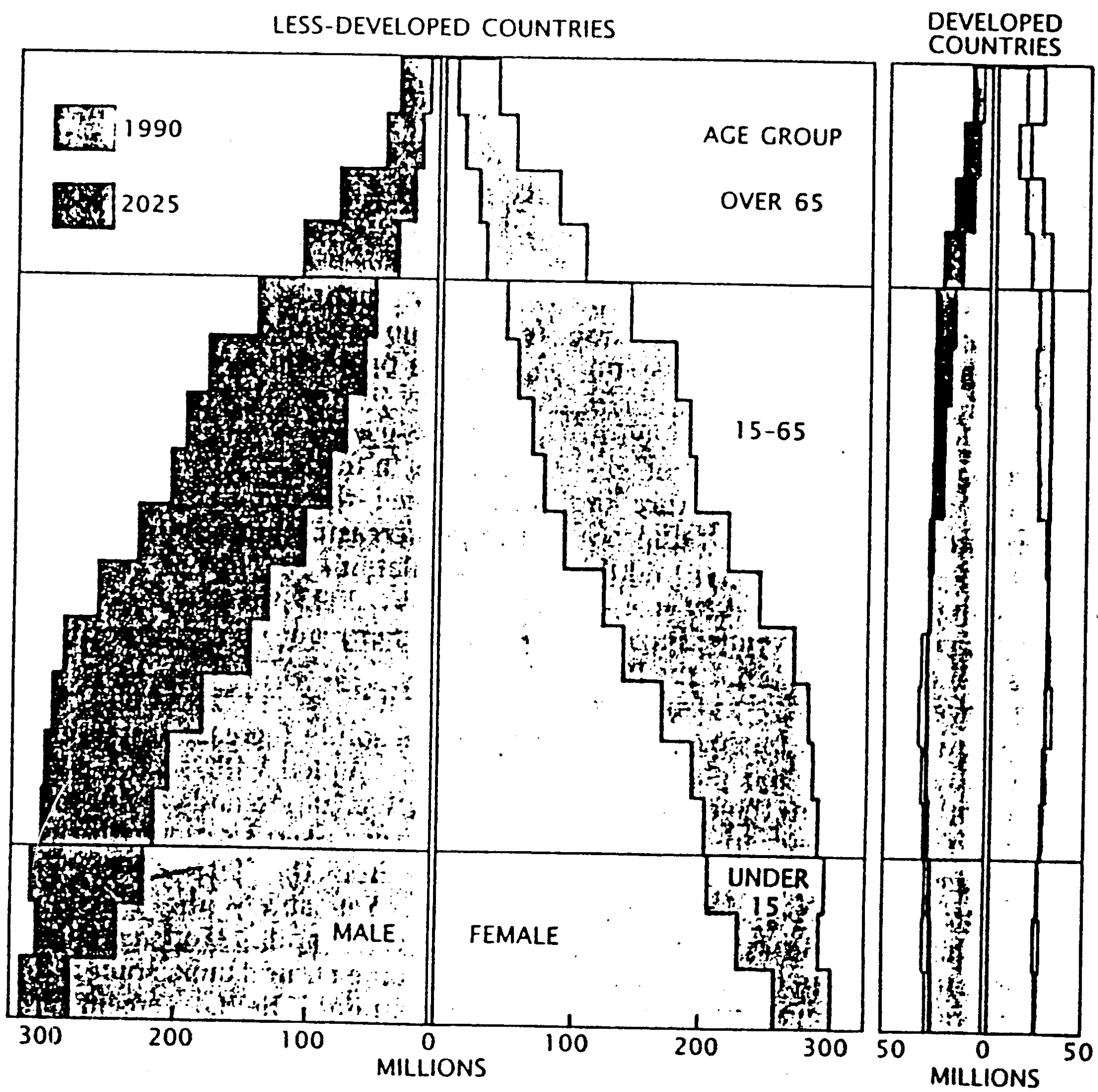

FIGURE 2. Age pyramids for developed and developing countries. (from Keyfitz 1989)

rate of a population characterized by its growth rate as *r*-selected, exponential growth to take advantage of resources, or as *K*-selected, growth controlled by feedback processes related to the environment's carrying capacity. The developed countries populations currently are in the stable, K-selected growth form due to what has been called the 'demographic transition'(Schneider, 1984, Keyfitz, 1989). According to Schneider the demographic transition has been known since the early twentieth century.

The various feedback mechanisms responsible for population control are related in figure 3. Feedback mechanism 1 in this model deals with populations with high birth rate and low death rate, such as the developing countries. It is the limit of available resources. Feedback mechanism 2 operates in populations which lower their birth rates due to their cultural controls triggered by various social indicators (the non-economic benefits or costs of children). Feedback mechanism 3 operates in populations with high birth rates and high death rates - the population suffers death rates higher than its birth rates due to the lack of necessary resources

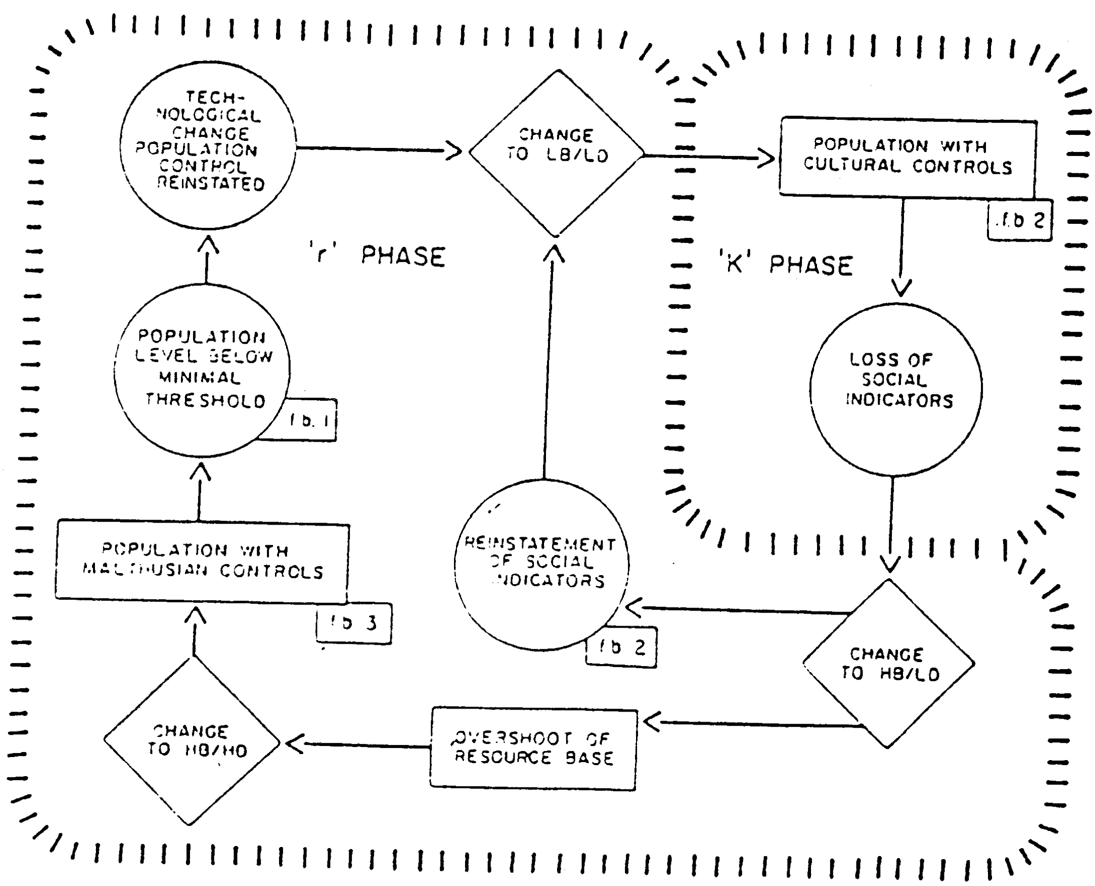

FIGURE 3. General Population Model. (from Boughey 1974)

or natural disasters.

Population size can be stabilized as shown by the current status of the developed countries and as described in the general population model.

Average Consumption

The average consumption of natural resources is a very important aspect of the impact a population has on its environment. Urbanization and industrialization in the developing countries will require increases in energy consumption (Dreyfus, 1990). Advanced technology could reduce the energy and raw material required per unit of product to overcome this drawback to development (MacNeill, 1989) if sustainable industry is encouraged.

Technology

Technology determines what resources are needed from the environment, how they are obtained, and ultimately what the limits of many resources will be. Our technological advances have been at the heart of population increases by making resources more abundant at lower cost, or finding substitutes for those resources which were exhausted. On a fundamental level technology is responsible for all the many advantages and comforts we enjoy. Only now can the environmental consequences of technology's success be realized.

Sustainable Human/Earth Ecosystem

The solution to the dilemma of how to support a much larger, more affluent global population than the present one will probably resemble the characteristics of a mature ecosystem. Table 1 shows some of these characteristics.

Agriculture will need to be more 'weblike' and less linear. The modern agricultural technology destroys complexity and replaces it with greatly simplified, highly managed monocultures which will be more susceptible to future disturbances such as changes in climate extremes. The simplified system is also prone to disturbance by pests and diseases which require difficult control responses. Modern agriculture also requires many outside inputs in terms of energy and fertilizer. Intense specialization will allow the maximum return to be achieved from the same amount of land. This would possibly be an efficient

TABLE ONE. Trends in the development of ecosystems. (After Odum 1962, after van der Ploeg, 1982)

Ecosystem attributes	Developmental stages	Mature stages
Community energetics		
1. Gross production/community respiration (P/R ratio)	Greater or less than 1	Approaches 1
2. Gross production/standing crop biomass (P/B ratio)	High	Low
3. Biomass supported/unit energy flow (B/E ratio)	Low	High
4. Food chains	Linear, predominantly grazing	Weblike, predominantly detrius
Community structure		
5. Species diversity - variety component	Low	High
6. Species diversity - equitability component	Low	High
7. Biochemical diversity	Low	High
8. Stratification and spatial heterogeneity (pattern diversity)	Poorly organized	Well-organized
Life history		
9. Niche specialization	Broad	Narrow
10. Life cycles	Short, simple	Long, complex
Nutrient cycling		
11. Mineral cycles	Open	Closed
12. Nutrient exchange rate, between organisms and environment	Rapid	Slow
13. Role of detrius in nutrient regeneration	Unimportant	Important
Selection pressure		
14. Growth form	For rapid growth ("r-selection")	For feedback control ("K-selection")
15. Production	Quantity	Quality

goal for the less developed countries as they will have the available manpower to manage this more complex agricultural system. What they will lack is the technology to determine what forms will be most efficient and the information management capability necessary to control a more complex agricultural ecosystem.

The biomass supported/unit energy flow relates to the efficiency of our relationship with the environment. It will be much easier to achieve sustainability if we can command the minimum proportion of resources for ourselves and leave as much as possible to the natural ecosystem to provide us with the environmental support services we rely upon.

Under community structure there are two types of species diversity, a variety component and a equitability component. Incorporating these aspects into our sustainable human/Earth ecosystem will mean the preservation of biological diversity and avoiding the displacement of as many species as possible. Diversity tends to create a stability in ecosystem conditions. The tropical rainforests are often cited as examples of stable diversity. A more complex ecosystem will also resist the outbreak of pests much more effectively than a simplified one.

All of the other attributes listed in table 1 have some analog with the characteristics we will have to emulate if we are to create our global ecosystem and provide a stable population with long, meaningful and enjoyable lives.

Disadvantages of Human/Earth Ecosystem

There are many problems to be overcome if the Human/Earth ecosystem is to be one which we can influence. The immediate needs of the large populations in the developing countries are often going unfulfilled today. Many of our institutions were created during the 'r-selected' era of population growth and are not adequate for the challenges ahead. Our knowledge of the earth's environmental systems has yet to reach the level of sophistication necessary to be the sole source of policy-making and global management of resources. While all these problems may be overcome given enough time, we may have crossed some irreversible environmental threshold we have not yet detected. The geologic record of mass extinctions in the past is an example, no matter what were their ultimate causes, that the current ecosystem may be replaced.

Conclusions and Recommendations

The most important conclusion from this examination of the consequences of population growth and the earth's environmental systems is that we lack crucial information about how our environment works. The environmental consequences directly attributable to our activities will have to be predicted and those predictions will have to be proven valid before widespread support can be enlisted for remedial action. Table 2 is a list of common ideas about climate change and what the actual facts tend to support. Any proposals about what to do about this problem will need to be considered very carefully before being accepted.

Another conclusion is that the exponential growth of population in the less developed countries has a great potential to disrupt the environmental system. The economic growth that will be required to stabilize their populations will be unprecedented and if

Table 2. Second Look at Climate Change. (from Ausubel, 1991)

1. Faster change is worse.	1. It is very important whether climatic change is expected.
2. Waiting to make policy and take action will drive up the costs of response.	2. It is very important how fast we can acquire better information.
3. There are only losers from climatic change.	3. There is likely to be a complex and shifting set of winners and losers.
4. The most important impacts will be on agricluture and from sea level rise.	4. There should be an increased focus on water resources an ecosystem preservation.
5. Changes in extremes will be more important than changes in means.	5. It is important to identify thresholds and discontinuities that may matter for impacts.
6. The changes envisioned are unprecedented.	6. It is important to clarify how greenhouse-induced climatic change will differ from all the climatic variations that already occur.
7. Impacts will be worse on less-developed countries than on developed ones.	7. There may be a double vulnerability of LDCs, both from climatic hazards and from strategies to limit emissions that may cause those hazards.
8. There are hedging strategies that are clearly economical.	8. The economics of hedging strategies need to be demonstrated.

misdirected could lead to severe global environmental changes. Allowing the less developed countries to overshoot their resources and letting high death rates control their numbers would be a tragedy.

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